IL 99/565

STATE PF ISRAEL

#5
PA
8/6/01

This is to certify that annexed bereto is a true copy of the documents as originally deposited with the patent application particulars of which are specified on the first page of the annex.

זאת לתעודה כי

רצופים בזה העתקים

נכונים של המסמכים

שהופקדו לכתחילה

עם הבקשה לפטנט

לפי הפרטים הרשומים

בעמוד הראשון של

הנספח.

**PRIORITY
DOCUMENT**
SUBMITTED OR TRANSMITTED IN
COMPLIANCE WITH RULE 17.1(a) OR (b)

This ———— 2 8 -10- 1999 ———— היום

רשם הפטנטים
Registrar of Patents

נתאשר

חוק הפטנטים, התשכ"ז–1967
PATENTS LAW, 5727–1967

בקשה לפטנט
Application for Patent

אני, (שם המבקש, מענו – ולגבי גוף מאוגד – מקום התאגדותו)
I (Name and address of applicant, and, in case of a body corporate, place of incorporation)

Shimon YANOWITZ, 43 Eastfield Avenue, Haxby, YORK YO3-3EZ, ENGLAND.

בעל אמצאה מכח ‏‏‏בהיותי הממציא‏
of an invention, the title of which is:

ששמה הוא: _____
Owner, by virtue of   being the inventor

(בעברית) מערכות אופטיות משוכללות
(Hebrew)

(באנגלית)
(English)

IMPROVED OPTICAL SYSTEMS

hereby apply for a patent to be granted to me in respect thereof.
מבקש בזאת כי ינתן לי עליה פטנט.

* בקשת חלוקה – Application for Division	* בקשת פטנט מוסף – Application for Patent of Addition		* דרישת דין קדימה Priority Claim		
מבקשת פטנט from Application	* לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No._____ מס'	No._____ מס'			
dated_____ מיום	dated_____ מיום			

* יפוי כח: כללי/מיוחד – רצוף בזה / עוד יוגש
P.O.A.: general / specific – attached / to be filed later –

Has been filed in case _____ הוגש בענין

המען למסירת הודעות ומסמכים בישראל
Address for Service in Israel

שמעון לביא, ת.ד. 6202, חיפה 31060
98073
Simon Lavie, P.O.Box 6202, Haifa

חתימת המבקש Signature of Applicant	היום 21 בחודש אוקטובר שנת 1998 199 This of 199

Simon Lavie   שמעון לביא

IMPROVED OPTICAL SYSTEMS

מערכות אופטיות משוכללות

Rotating Optics

1 Abstract

A method and an apparatus are provided for restoring the quality of circular symmetry to an optical system, or to a part thereof. This results in better system performance and specifications, and has additional advantages and benefits as described hereinafter. The method and apparatus take advantage of the System's finite, non-zero exposure, or integration time, during which period the symmetry restoration is performed. The method and apparatus utilize a means of rotating the optical system, and a control system that synchronizes the speed of rotation with the exposure time, such that as near a symmetry as possible, is restored. Means are also provided for alignment of the optical axis with respect to the mechanical axis of rotation.

A simpler method and apparatus are also provided, which have less optical benefits then the first method and apparatus, but which have the benefit of simplicity. The latter said method and apparatus are suitable and beneficial in particular, to measurement tools, such as overlay metrology and other measurement tools, which employ an optical viewing system. This method does not require as accurate an alignment of the optical axis as the first method, since the rotation is performed in stops rather than a continuos motion.

2 Background of the Invention

2.1 Field of the Invention

This invention relates to optical systems, tools and instruments. It also relates to other systems, tools and instruments, having optical components or optical sub-systems. The invention relates in particular, to optical systems and sub-systems that are used for viewing or for projection of images.

2.2 Description of Related Art

2.2.1 Challenges Imposed on Optical Technology by the Semiconductor Industry

Contrary to recreational uses of optical viewing or projection systems, Some applications require the technology of design and manufacture of such systems to be pushed to its very limits. One typical application that requires this is the process of semiconductor device fabrication. The devices are fabricated on Silicon wafers, where every wafer can hold multiple devices. Every wafer is made up of multiple layers that are overlaid, in sequence, on top of each other. The repetitive step of producing a single layer involves a process called *photolithography*. In such a process a machine called a *stepper* is used to optically project patterned slides called *masks* on a coating of a light-sensitive layer called photo-resist, that is deposited on the Silicon wafer. The exposed photo-resist layer is than developed, leaving a pattern of photo-resist on the wafer, that matches the pattern of the mask. This pattern serves as the basis for producing the layer. Once the layer is finished, photo-resist can be, again, deposited on the wafer and another layer can be produced.

The ever-increasing technological requirements on the complexity and speed of operation of semiconductor devices imply that these wafer patterns must contain extremely fine features, a fraction of a micron wide. The width of the finest pattern on a wafer is known as the *design rule*. The size of the design rule has been declining rapidly (by about a factor of 10) over the last decade. Whereas the fastest devices being sold today are using a 0.25-micron design rule, new

devices are already being developed using half that size. This requirement translates to a requirement on the op● quality of the stepper's optical system ● articular, this system is required to produce a●●age whose level of geometrical distortion is much smaller than the width of the finest patterns to be produced. In addition, the level of resolution of this image must be a lot finer than the smallest patterns.

Another implication of the semiconductor device technology is that the features that are printed on one layer of the wafer must align well with other features, produced underneath them, on preceding layers. The error of alignment between the layers is called an *overlay* (or *misregistration*) *error*. The maximal allowed overlay error is known as the *overlay budget*. The overlay budget is about one third of the design rule.

Another tool called an *overlay* (or *registration*) *metrology* tool operates in conjunction with the stepper. This tool employs a microscope that is used to view the patterns created by the stepper. By viewing patterns belonging to different layers, and analyzing the image in a computer, the tool is able to measure the overlay error between the layers. The measurements performed by the overlay metrology tool are used to test, calibrate and adjust the stepper to minimize the overlay error. The overlay tool, however, introduces an error of its own to the overlay measurement. This error consists of two components known as the *repeatability error* and the *accuracy error*. The latter is also called *Tool Induced Shift* (or *TIS*). This error arises directly from distortions and aberrations in the optics of the overlay tool. The repeatability error, on the other hand, can originate from several contributions, with the optics being one of them. Since the overlay tool is used to monitor and control the stepper, the tolerances placed on its combined error are a lot tighter. Whereas the stepper must produce an overlay better than the overlay budget, the overlay tool must in turn, produce a total error limited to about one tenth of that. This allowed error, and especially its TIS component, translates to extremely strict requirements on the optical quality of the overlay tool.

Another metrology tool that is used to test and calibrate the stepper is the *critical-dimension (CD) metrology* tool. This told is used to measure the width of the finest lines that are produced by the stepper. Although nowadays, line-width tools mostly employ electronic microscopes, rather than regular optical systems, the latter are still used at times. Other types of measurement tools that employ optical systems may also be used.

Thus, the constant drive to increase the complexity and speed of semiconductor devices places the tightest possible constraints and tolerances on the optical technology and quality of the stepper and the metrology tools used in their fabrication process. This quality is what determines and limits the achievable complexity and speed of today's devices.

2.2.2 Prior Art of Optical Design and Manufacture

In an ideal world, all optical systems that are used for viewing or projecting planar fields would treat every point in their respective field of view, or field of projection, in an equal manner. All points in that field would be in focus simultaneously, would be equally magnified and there would be no distortion in the image. In the real world, unfortunately, This cannot be achieved even in theory. The laws of physics imply that even if all the basic components (i.e. lenses) that make up an optical system were perfectly made and assembled, the systems as a whole would still deviate from that ideal behavior.

The art of optical design attempts to correct and compensate for these deviations in order to minimize them. By designing a more complex (and more expensive) system, it is possible, in theory, to get as close as is required, to the ideal behavior.

However, besides the design, other arts are involved, namely the arts of manufacturing the lenses- the basic glass components, and the art of assembling them the final optical system. Unfortunately, as an optical system becomes more complex in its design, there is a lot more that can go wrong when it is actually put together.

No matter how much care and cost goes into their production, the system's individual glass components (lenses) always contain impurities, blemishes and imperfections, and care must be taken so that these do not violate the required quality and tolerances. In addition, every polished glass surfaces has some fine irregularity. There could also be slight deviations from the required shape, known as *form errors*. Verification of the quality of the individual lenses also requires very elaborate and time consuming inspection, and even with the best of instrumentation, it is impossible to detect all the imperfections. At times, there could be a 0% yield, or a 100% rejection ratio, meaning that all the lenses in a batch have been found to violate the tolerances. The manufacturer of the system may then be forced to use sub-optimal components since production cannot continue otherwise.

When the individual glass elements are ready, there comes the very elaborate and skillful task of assembling them into the final system. A typical case of a microscope objective is illustrated in **Figure 1**, which depicts a schematic cross-section through such an objective. As illustrated, cement 10 is used to secure the glass lens 11 in its metal holder, called a *cell* 12. Various cells are then assembled into some sort of mechanical casing, like a tube 13, or other.

The assembly process is never perfect. Further imperfections are introduced, and further deviations from the required behavior are inevitable. **Figure 2** illustrates typical deviations that occur when lenses are placed in their cells. Lens 21 is perfectly placed in its cell 25. Lens 22 has a lateral displacement with respect to the cell. Lens 23 has an angular displacement. Lens 24 is part of a compound lens called a *doublet* and deviates in position and angle with respect to the other lens 26 of the doublet and the cell.

Figure 3 illustrates further deviations that typically occur when the finished cells are inserted into a tube or some similar case. . Cell 31 is perfectly aligned with respect to tube 34. Cell 32 is laterally displaced with respect to the tube. Cell 33 has an angular deviation with respect to the tube. Any deviations in the locations of the cells introduce deviations in the locations of their respective lenses, further to those already incurred during the mounting of the lenses in the cells.

These non-ideal factors cause the actual optical system to deviate from the ideal model and give rise to various aberrations and disturbances, like coma and astigmatism. A common practice to reduce the level of aberrations in an optical system is to stop it down by means of an aperture. However, this has the negative effect of reducing the optical resolution of the system. This resolution is proportional to the *numerical aperture* (*NA*) of the system, which decreases with the physical aperture size. Whereas stopping down a lens in a recreational application is quite acceptable, it may be totally unacceptable in the leading edge technology of semiconductors. This is because the sizes of features to be viewed or projected on a wafer, is at the very limit of resolution of the optical systems used in the process.

The deviations and imperfections introduced during the manufacture and assembly of the basic lenses may add up to such a degree that the final optical product fails to meet its specification and has to be rejected. As mentioned, the risk of this happening increases, as the system is more complex. The cost implications of rejecting an assembled system, after all the material and labor have gone into it, can be outstanding.

Shipment of an optical system poses yet another mechanism whereby things can go wrong. During shipment, the system might be exposed to mechanical shocks, severe pressure changes (if shipped by air) and severe temperature changes. It is often the case that a system meets its

specifications and qualifies well in production, but then changes considerably and goes out of spec upon reaching its ●nation.

It follows that increasing the design complexity of an optical viewing or projection system, in order to make it of a sufficient quality on paper, does often fail to achieve the required quality in the final product. This still holds even if the production time and costs rise considerably. Even if the customer is willing to pay a very high price for the product and wait a very long time for its delivery, there may still be no guarantee that the required specifications and tolerances can be met.

3 Summary of the Invention

The present invention aims at providing means of circumventing many of the ailments of optical systems, as discussed in the prior-art section, thus boosting the quality, performance and value of such systems.

The invention identifies as a principle, that optical systems or parts thereof, should ideally have the quality of circular symmetry, but that in fact, they fail to achieve this quality. Restoration of this lost circular symmetry is identified as benefiting to the quality and level of performance of an optical system.

There is always a finite, non-zero, period of time, in which a viewing or projection system is required to generate an image. This period is known as the exposure time. This invention identifies as another principle, that it is possible to take advantage of this time to "blur", or spread local blemishes in the optical system, over a larger imaging area. By doing so, the effect of the blemishes and imperfections is reduced, and thus the quality of the system is improved.

A method is presented, that combines these two principles. According to this method, the optical system is rotated about its optical axis, during the exposure time. By doing so, the blemishes of the system are spread over a full circle, whereas an image that is either viewed or projected through the system, remains intact. The rotation speed is synchronized with the exposure time, such that the system completes a whole number, preferably exactly 1, of rotations during the exposure time, and thus optimal uniformity of spreading is obtained.

An apparatus is presented that performs the rotation of the optical system, comprising a pivoting mechanism, such as a bearing and a means of actuating the rotation, such an electrical motor. For the optical system to rotate exactly about its optical axis, it is necessary to align the optical axis with the mechanical axis of rotation. For achieving this, the apparatus comprises means of moving the optical system in the x-axis and y-axis directions, at two different points, altogether providing four degrees of freedom. This is achieved by using means capable of actuating very fine linear motions, such as piezo-electric transducers, such as flexures, for translating these linear motions, to motions of the optical system in the x and y axes. The rotated optical system is connected to the axis control mechanism, by means of couplers, such as self-aligned bearings.

The mechanical alignment system is governed by an electronic system, comprising means of controlling the linear actuators, such as a piezo-electric transducer controller. The electronic system is governed by a computer and a software program. The system also comprises means of viewing an image that passes through the optical system, and of providing this image in digital form to the computer, such as a camera and image frame-grabber. The software program analyzes the images for sharpness or some other criteria for image quality, and causes the computer to instruct the actuator controller to change the position of the system, such that the quality of the image is optimal. This combined system is capable of much better alignment than is achieved with normal production tolerances.

Another, simpler, method is presented which does not have all the benefits of the advanced method, but which requires a much simpler apparatus. This method is suitable for viewing systems. It is especially useful for image analysis and measurement tools, such as overlay measurement tools. According to this method, the optical system is rotated in stops, rather than in a continuous motion. A whole number n, (at least 2) of stops are made, where in each stop a new image is captured and an analysis, such as a measurement is performed on it. This produces n independent analysis, which are all biased due to some tool error. However, the error at each stop points to a different orientation. Therefore, it is possible to process the different results in some way, such as averaging, to produce a single, combined result, in which the effects of the error vectors cancel out. The accuracy of the analysis, such as a measurement result, is thus greatly improved.

A simpler apparatus is presented, which may replace the advanced apparatus in some cases. This simpler apparatus is particularly suitable for the latter simpler method. Manual adjustment is used instead of the electronically controlled alignment system of the advanced apparatus, and means such as screws, replace the fine linear motion actuators. With these screws, or similar means, a coarser alignment is achieved, but this is acceptable for the simple method, as long as the target being focused upon remains roughly in the center of the field of view during the rotation.

The following advantages and benefits are derived from the invention:
1. The invention improves the quality of an optical system, through reduction of asymmetrical aberrations, such as coma, reduction of distortion and astigmatism and reduction in the effect of blemishes and impurities. This allows for better performance and tighter specifications, raising the value of the system.
2. Due to the elimination or reduction of said ailments, the system matches its theoretical design model better, and becomes more predictable. This allows for designing more cost-effective solutions.
3. Use of this invention allows acceptance of components and systems that would otherwise have been rejected. This results in substantial savings.
4. The invention can reduce the production time and effort required to achieve the specifications, and allows for lower production costs and shorter delivery times.
5. The invention can improve the stability and reliability of the system over long term.
6. The invention reduces the risk of system failure due to effects of shipment and of environmental conditions.
7. The invention allows increasing the Numerical Aperture of the optics, thus increasing its optical resolution and its ability to view or project finer patterns. This further boosts the specifications and value of the system.
8. For measurement systems, such as overlay metrology tools, the invention improves the accuracy and reduces the tool induces shift (TIS).

4 Brief Description of the Drawing

Figure 1 depicts a schematic cross-section through a typical microscope objective.

Figure 2 is a schematic illustration of typical deviations that occur when lenses are mounted in their cells.

Figure 3 is a schematic illustration of typical deviations that arise when cells are encased in a tube or a similar covering.

Figure 4 illustrates two basic lenses, a convex lens and a concave lens, with their respective axes of symmetry.

Figure 5 is a schematic example of an optical system were several lenses are stacked together in a column such that their optical axes coincide to form a common axis.

Figure 6 is an isomet▪ ●iew of an example layout of the mechai   nd optical axes of an optical system in the thr ●mensional space.

Figure 7 depicts a schematic mechanical layout of a simple embodiment of the invention.

Figure 8 depicts a schematic mechanical layout of an advanced embodiment of the invention.

Figure 9 is a schematic layout of the optical system with its electronic control system.

Figure 10 is similar to **Figure 9**, but depicts a layout more suitable for a projection system.

Figure 11 depicts a schematic example of a folded optical system.

5 Detailed Description of the Preferred Embodiment

5.1 *The Principle of Circular Symmetry*

The vast majority of optical systems comprise basic lenses and mirrors, polished such that one or two of their surfaces are spherical. On rare occasions, these could be parabolic surfaces. All these lenses have an axis of symmetry, which is called the *optical axis*. **Figure 4** illustrates two basic lenses, a convex lens 41 and a concave lens 42, with their respective axes of symmetry 43.

One important foundation of this invention is the principle of rotation symmetry: Consider the simplest possible optical system, a system consisting of only one lens, one of the two shown in **Figure 4**. Assume that the lens is perfect (i.e. does not have any blemishes or form errors). As an optical system, this would be of poor quality. It would exhibit spherical aberration, chromatic aberration, pincushion or barrel distortion and field curvature. This simple system, however, has a certain special quality. It has the quality of circular or cylindrical symmetry. What this means is that the lens has no preferred orientation with respect to its optical axis. It can be freely rotated about its axis with no effect whatsoever on its optical behavior. The aberrations and distortions produced by this lens are also circularly symmetric.

Practical optical systems or parts thereof, are made up of several basic lenses, each with concave and convex surfaces similar to those in **Figure 4**. Some systems may also have mirror elements in addition to, or instead of lenses. Each of these lenses and mirrors may have a different radius of curvature and lenses may consist of a slightly different glass material. This is done in an attempt to correct and compensate for the different aberrations, the distortion and the field curvature of the entire system. The elements are assembled together in a column such that their individual optical axes coincide to form the common optical axis of the whole system. A schematic example of such a system is shown in **Figure 5**, where the various lenses 51, form a column with a common optical axis 52.

If all the lenses in a compound system or sub-system, like the one in **Figure 5**, were perfect and if the assembly was, also perfect, the entire system or sub-system would also have the quality of circular symmetry. The entire system could be freely rotated about its optical axis without any effect on its optical characteristics and performance. Unfortunately, this can never be the case, because neither the lenses nor the assembly can ever be perfect. Paradoxically, the deviation from the ideal symmetry is likely to be greater as the design becomes more elaborate and complex, since the system has more glass elements that contribute more deviations.

There are three major contributing factors for lack of circular symmetry in an optical system:
1. The glass, of which every basic lens in the system is made, always has impurities and imperfections in it. Such blemishes are scattered randomly in the material and disrupt the uniformity of the glass, and hence the symmetry of the lens.
2. Each lens is produced in a polishing process in which a flat piece of glass is polished down in an attempt to create spherical surfaces. However the resulting surfaces are not perfect and always have some surface irregularity, which is random and can never be symmetric. In

addition, there are ⬤ ays form errors. There can be symmetric form errors as well, but there are always so ⬤ asymmetric form errors. Thus, the symm ⬤ of the lens can never be perfect.

3. When assembling all the individual lenses into the final optical system, each lens has to be perfectly aligned about the common axis of symmetry- the *optical axis* of the system. However, both lateral and angular deviations are inevitable, as discussed in the related art section, and illustrated in **Figure 2** and **Figure 3**. These violate the circular symmetry of the whole system.

The purpose of this invention is to restore this lost circular symmetry to the optical system. By doing so, the quality and performance of the system are improved. In addition, the system's behavior becomes very close, if not identical, to the theoretical model of its design, and is thus predictable. Note that the system can never be better than its theoretical optimum. However, how close we can get to that optimum is what makes the difference.

5.2 The Principle of Exposure-Time Integration

Another foundation of this invention is the principle of exposure integration: In normal use, there is always a finite, non-zero, amount of time, in which a viewing or projection system is required to generate an image. When projecting an image, for example, the light source that passes through the image-slide, remain on for a certain period. Similarly, when taking a picture, the image is being formed for as long as the camera's aperture remains open. This period is known as the *exposure time*.

The formed image is an integral of all the instantaneous images that are viewed by the optics during the exposure. In the case of using an electronic CCD (Charge Coupled Device) camera, the exposure time is also referred to as the *integration time*.

The integration that occurs during the exposure is often treated in the art, as very undesirable. When taking a picture, for example, a too long exposure time (or a too slow aperture speed) can cause blurring, or smearing of the subject.

However, this invention takes advantage of this exposure period and benefits from it. The idea behind this is that it is possible to smear and blur not the subject, but rather the blemishes in the optics.

5.3 Combining the Two Principles: Rotating the Optics

To combine the two above principles, this invention introduces the method of rotating the optical system about its optical axis. This rotation is synchronized with the exposure time. Although other modes will be suggested, in the synchronous mode of operation the rotation speed is adjusted such that exactly one rotation is completed during the exposure time of the system. This way, the blemishes and deviations are integrated and spread evenly over a full 360 degrees circle. If it weren't exactly one full rotation, the spread would not be even. This rotation method is analogous to the way a drill operates: The drill has a distorted shape that lacks circular symmetry. However, by rotating the drill, it is possible to create a symmetric hole.

Rotating the optics would be considered in the art, as harmful and undesirable. This is because it would seemingly destabilize the viewed or projected image, and could potentially lead to blurring of the features of that image. However, the embodiment of this invention does not necessitate any such damage, as explained hereafter.

5.4 Axis Alignment

One mechanical obst[...]as to be overcome: We have to rotate[...]optical system about its own optical axis. However, as explained in the prior art discussion and illustrated in **Figure 2** and **Figure 3**, the optical axis will always deviate to a certain extent, from the mechanical axis. **Figure 6** is an isometric view of an example layout of the axes in the three dimensional space. The mechanical axis of rotation 61 is placed along the z-axis. The optical axis 62 is misaligned with respect to the mechanical axis. In order to align the two axes, the optical axis is held in two points 63 and 64. These points have to be moved in space by the two respective vectors 65 and 66. These vectors are illustrated along with their respective x-axis and y-axis components. Altogether, we need four controls: Two for the x-axis and two for the y-axis. Note that in reality, the offset between the two vectors in the x and y axes, is going to be in the order of microns, because the present art of optics manufacturing is capable of this level of accuracy. The z-axis separation between the two points 63 and 64, on the other hand, which is the length of the system, is going to be in the order of centimeters or more. This means that effectively, points 63 and 64 need not move along the z-axis at all.

Another problem is that it is impossible to determine the exact position of the optical axis in advance, since this position is affected by various unknown deviations, which were introduced in the manufacture and assembly process, as described previously. It follows that a calibration process needs to be performed in-situ, in order to carry out the alignment between the optical axis and the mechanical axis.

5.5 A Simple Embodiment

Figure 7 depicts a schematic mechanical layout of a simple embodiment of the invention. As shown, a case, containing the optical system, such as a tube 71, is put in a sleeve 72. The sleeve is mounted in a bearing 73, shown with its housing 74, which forms the mechanical axis of rotation. The sleeve is rotated by preferably an electrical motor 75, through a transmission 76. Other methods of actuating the rotation, such as hydraulic or pneumatic actuation, are possible. The position of the tube relative to the sleeve is adjustable by two sets of adjustment screws 77 and 78. Each set comprises four screws, two for the x-axis and two for the y-axis (only the x-axis screws are shown). Note that three or more screws are acceptable, however, four screws per set are preferred. Other means of adjustment are acceptable. This embodiment requires manual adjustment to align the optical axis with respect to the mechanical axis.

5.6 A simple Mode of Operation

The accuracy of axis alignment, provided by the simple embodiment of **Figure 7**, might be too coarse for some applications. This is because there is a limit to how fine the pitch in the thread of the adjustment screws can be. However, one particular mode of operation that doesn't require a lot of accuracy. In this mode, the optical system is not rotated continuously, but rather- in stops.

In the case of overlay metrology for example, as described in the related art section, the viewed image is used to measure the magnitude and direction the overlay (misregistration) error between two layers. The misregistration is a planar vector with x and y components. If the image is distorted slightly by the optics, the measurement will produce a slight error. As mentioned, this error is called TIS (tool induced shift). This error is also a vector. As an approximation, if we rotate the optics by 180 degrees and take a second measurement, the error vector will point to the opposite orientation. The average of the two measurements will cancel out the error will thus give the true misregistration value.

An even better approximation is achieved if we rotate the optics 90 degrees at a time, and take four measurements to be averaged. This way the optics affects the x and y components of the measurement equally. The general case is to take a number-n measurements at fixed intervals over a full circle, and average, or otherwise mathematically process the results. Note that pausing a few times to take several measurements, has the penalty of reducing the throughput of the tool.

As mentioned, In this mode of operation there doesn't need to be a perfect alignment of the optical axis with respect to the mechanical axis. The image might move slightly within the field of view, between the measurements, because of slight misalignment. However, this is of no particular concern in this mode of operation, because every measurement uses a different image. The system pauses before capturing each image and there is no blurring due to integration. The level of accuracy of the alignment in this case has to be such that the target being focused upon remains in the field of view of the tool's camera during the rotation.

Whereas this mode does not offer the full benefits of full circular symmetry, it does offer some benefits, as discussed above, at a far greater simplicity. There doesn't need to be synchronization between the rotation speed and the exposure time. There also doesn't need to be perfect alignment between the mechanical and optical axes. This results in a simpler mechanical structure, as shown in **Figure 7**, compared with **Figure 8**. In addition, much less care needs to be taken in assuring the stability of the system.

5.7 *An Advanced Embodiment*

Figure 8 depicts a schematic mechanical layout of an advanced embodiment of the invention. As shown, a case containing the optical system, such as a tube 81, is put in a sleeve 82, to which it is connected by means of a ring 83 of metallic flexure or elastic material, or by any other means, capable of providing the slight freedom of movement that is required to align the tube with respect to the sleeve. The sleeve is mounted in a main bearing 84, shown with its housing 85, which forms the mechanical axis of rotation. The sleeve is rotated by preferably an electrical motor 86, through a transmission 87. Other methods of actuating the rotation, such as hydraulic or pneumatic actuation, are possible. The tube is also attached to two self-aligned bearings 88 and 89, at either side of the main bearing. These two bearings are mounted in pre-loaded flexures, 810 and 811, both of which are capable of moving in the x and y directions. The flexures are actuated by two sets of piezo-electric transducers 812 and 813. Similar, accurate transducers can also be used. Each set comprises two transducers, one for the x-axis and one for the y-axis (only the x-axis transducers are shown). Note that a larger number of transducers may be used.

The piezo-electric transducers are devices that change their length in relation to the electric voltage applied to them. These devices are capable of moving the optical axis in extremely fine sub-micron resolutions. This is by far finer than any production-set tolerance can achieve. Similarly, this embodiment offers a much greater degree of accuracy than is available with the simpler embodiment of **Figure 7**.

In addition to restoring the circular symmetry, this embodiment has another advantages over conventional systems. As discussed in the prior art section, any optical system is prone to drifts over time and to changing during shipment, which inadvertently affect its performance. With conventional factory-sealed systems, such changes might be impossible to control. This embodiment offers the capability to calibrate and adjust the system anytime such an adjustment is required.

In order to carry out the fine alignment of the optical axis with the piezo-electric devices, a special computerized control system is required. **Figure 9** is a schematic layout of the optical system with its electronic control system. The piezo-electric transducers are activated by an electronic control system 91. The optical system is positioned to focus on some pattern 92. An electronic camera 93 is mounted on the system. The electronic image of the camera is captured by a digital frame-grabber 94. The frame grabber is connected to a computer 95. A software program that runs on the computer analyses the digital image for sharpness. The same computer and software also control the electronic system 91 that actuates the piezo-electric transducers, thus forming a closed-loop control system. The system changes the positions of the piezo transducers, until the sharpest image is obtained. Similar criteria can also be used. The computer also controls the speed of the motor by means of an electronic motor-control system 96. The speed of the motor is synchronized with the exposure time of the camera.

Note that if the optical system is used for viewing, it already has a camera and a frame grabber, without which no automated viewing can take place. If, on the other hand, the system is used for projection, it might not employ a camera and a frame grabber, or it might employ a camera and a frame grabber, but not through the main optics. In this case, the designer might elect to add these components and to use the system as a viewing system just for the purpose of calibration and alignment. Another option is to place the camera and frame grabber such that they view the projected. This solution is depicted in **Figure 10**. As shown, a beam-splitter 101 is placed at the front of the optics such that the projected image 102 is also viewed by the camera 103.

5.8   Advanced Modes of Operation

5.8.1   Synchronous Mode

A synchronous mode of operation is achieved when the rotation speed of the optical system is controlled by the electronic system of **Figure 9** such that exactly one rotation is completed during the exposure time of the camera or projector. Note that any whole number greater than one is also acceptable. However, it is desirable to limit the speed as much as possible for stability purposes. Therefore, one rotation exactly is preferred.

Unlike the simple mode described previously, this mode restores full circular symmetry to the optics. The cost of this is the added complexity of the mechanical and electronic systems.

5.8.2   Asynchronous Mode

An asynchronous mode of operation uses the same advanced system embodiment as the synchronous mode. The difference is that the control of the rotation speed is relaxed and is only coarsely controlled. In order to achieve a relatively even spreading of the optics, however, the system has to complete a large number of rotations during the exposure time. For example, if the optics does around 100 rotations during the exposure time, it matters very little if this number changes to 99.5. It means that half the circle receives 0.5 percent more exposure than the other half. The spreading is not perfect then, but it may be enough. By contrast, if the number of rotation changes from 1.0 to 0.5, the difference becomes 50 percent.

The penalty for the relaxed control of speed is that as explained, the rotation speed should be a lot higher than with the synchronous mode, and the moment of inertia of the mechanics needs to be controlled a lot tighter. Failing to control it sufficiently might result in harmful mechanical vibrations.

5.9 Folded Optical Systems

Some optical systems are folded over once or more. This folding is achieved by means of mirrors, beam-splitters, or both. **Figure 11** depicts a schematic example of an imaginary folded projection system: Light from source 111 passes through the mask (slide) 112. After the condensor 113, the optical axis is folded by 90 degrees to the left (upwards) by the beam-splitter 114. The axis is folded again by 180 degrees (downwards) by a parabolic mirror 115. It is then focused by the final objective 116 on the target 117. The designer of this sytem may want to rotate all the componnents marked by dashed lines in this illustration. Note that the light source and the condensor are not on the same potential axis of rotation as the objective, because of the 90 degrees fold. On the other hand, the parabolic mirror is on the same axis as the objective, because of the 180 degrees fold.

It is obvious that in folded systems it might not be possible to rotate the optics as one. The designer has two options in such cases. The first option is that each sub-system be rotated separately by its own rotation mechanism. As a second option, the designer might elect to concentrate on part of the system that is more critical than the other parts, and rotate that part only. Note that this invention is applicable not only to whole optical systems, but also to parts thereof.

6 Claims

1. The principle of restoration of the quality of circular symmetry to an optical system or to a part thereof.
2. The principle of spreading and reducing optical aberrations, distortions and blemishes of an optical system, or a part thereof, through exposure time integration.
3. A method for improving the quality, performance and value of an optical system, or a part thereof, by restoration of the quality of optical symmetry said in claim 1.
4. A method for improving the quality, performance and value of said optical system, or a part thereof, by utilizing the exposure time integration spreading said in claim 2.
5. A method of carrying out the restoration said in claim 1, by rotating said system or a part thereof, with respect to its optical axis.
6. A method of carrying out the spreading said in claim 2, by rotating said system or a part thereof, with respect to its optical axis, during said exposure time.
7. A method of simultaneously combining the methods said in claim 4 and claim 6, by accurately controlling the speed of said rotation with respect to said exposure time, such that there is exactly a whole number n, equal to or greater than 1, of rotation cycles during said exposure time.
8. A method of simultaneously combining the methods said in claim 4 and claim 6, similar to the method said in claim 7, but an approximation thereof, by loosely controlling the speed of said rotation with respect to said exposure time, such that there are multiple cycles of rotation during said exposure time.
9. A method of approximating the quality of circular symmetry said in claim 1, of an optical projection system, by rotating said optical system, or a part thereof, preferably over a full circle, with a whole number n, equal to or greater than 2, of stops, at equally or unequally spaced angular intervals, where in every stop a new image is projected.
10. A method of approximating the quality of circular symmetry said in claim 1, of an optical viewing system, used for image analysis, comprising the steps of:
    i. Rotating said optical system, or a part thereof, preferably over a full circle, with a whole number n, equal to or greater than 2, of stops, at equally or unequally spaced angular intervals, where in every stop a new image is viewed, thus producing n independent images.

    ii. Performing said analysis on each image individually, produc███ n independent analysis-results, whic███ then processed according to some ███thm, to yield a single combined ana███ result.

11. A method for improving the accuracy and the precision, and for reducing the TIS (Tool Induces Shift), of measurement tools, such as an overlay metrology tool, which employ an optical viewing system, comprising the steps of:
    i. Rotating said optical system, or a part thereof, preferably over a full circle, with a whole number n, equal to or greater than 2, of stops, at equally or unequally spaced angular intervals, where in every stop a new image is viewed, thus producing n independent images.
    ii. Performing said measurement on each image individually, producing n independent measurements, which are then averaged, or otherwise mathematically processed, to produce a single combined measurement value.

12. A mechanical apparatus for carrying out the rotations said in claim 4 through claim 11, comprising:
    i. A case, such as a tube, containing the optical system or a part thereof.
    ii. A means, such as a sleeve, to serve as a mount for holding said case inside a bearing or other rotation mechanism, allowing some fine adjustment of the position of said case inside said mount.
    iii. Means of fine adjustment of the x-axis and y-axis position of said case inside said mount at two different points along the longitudinal axis (z-axis) of said mount, such as two sets of adjustment screws, where each set comprises at least three.
    iv. A means capable of rotating, such as a bearing and its housing, holding said mount.
    v. A means, such as an electrical motor, of actuating a rotation of said mount.
    vi. A transmission, connecting said mount to said means of actuating the rotation.

13. A method of aligning the apparatus said in claim 12, by viewing an image of some test pattern through the optical system, either directly, or by a camera and a display system, or an automated image analysis system, and by manually adjusting said means of fine adjustment such that it is either observed, or indicated by said automated image analyses system, that said image remains as still as possible during said rotation.

14. A mechanical apparatus for carrying out the rotations said in claim 4 through claim 11, comprising:
    i. A case, such as a tube, containing the optical system or a part thereof.
    ii. A means, such as a sleeve, to serve as a mount for holding said case inside a bearing or other rotation mechanism, allowing some fine adjustment of the position of said case inside said mount.
    iii. A means, such as a flexure or some elastic material, for connecting said case to said mount, such that said case is capable of fine movements inside said mount.
    iv. A means capable of rotating, such as a bearing and its housing, holding said mount.
    v. A means, such as an electrical motor, of actuating a rotation of said mount.
    vi. A transmission, connecting said mount to said means of actuating the rotation.
    vii. Means such as two self-aligned bearings with housings, capable of rotating and of slightly adjusting the axis of rotation, holding the case said in (a) at two different points along the longitudinal axis (z-axis) of said case, to serve as two links for the axis alignment system.
    viii. Means, for axis alignment, such as two x-y flexures, holding said links, and which are capable of fine adjustment of the positions of said links, in the x and y axes.
    ix. Means, such as two sets of piezo-electric transducers, to serve as actuators of said means of axis alignment, comprising at least two transducers in each set.

15. An electronic Apparatus, which operates in conjunction with the mechanical apparatus said in claim 14, comprising:
    i. A means of controlling the actuators said in claim 14 (ix), such as an electronic piezo-electric transducer controller.

ii. A computer, ꞁ governs said controller, on which a control software program is running.

iii. Means of viewing an image and providing it in digital form to said computer, such as a digital camera and image frame grabber.

iv. A means of controlling the motion and speed of the actuator of rotation said in claim 14 (v), such as an electronic motor controller, which is also governed by said computer.

16. An apparatus similar to the apparatus said in claim 15, which is, however, more suitable to projection system, which comprises an additional means, such as a mirror or a beam splitter, allowing an image projected through the rotated optical system, or a part thereof, to be viewed by said means of viewing, such as a camera.

17. A method of using the electronic apparatuses said in claim 15 and claim 16, to align the mechanical apparatus, said in claim 14, comprising the steps of:

i. Focusing said optical system on some test pattern.

ii. Viewing the image of said pattern, which passes through the optical system, or a part thereof, by said means of viewing, such as a camera and frame grabber, such that said image is available in digital form to said computer, and said software program running on said computer.

iii. Analyzing said image by said computer program, according to criteria for image quality such as sharpness.

iv. Using said computer and program to change the position of said means of axis alignment, through said actuator controller, such that a best image quality is achieved.

18. An application of any of the principles, methods and apparatuses said in claims 1 through 17, to any optical system or to a part thereof.

Shimon YANOWITZ

/ Shimon han

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: +972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

7 Figures
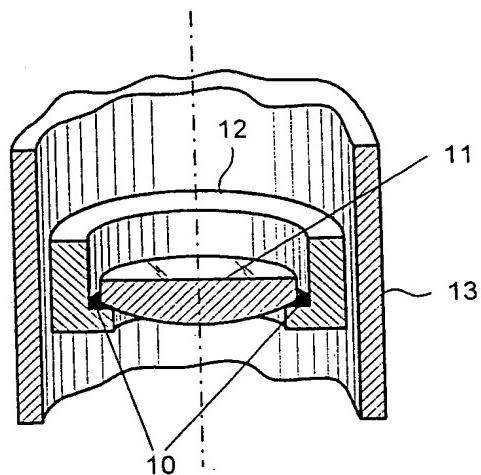
Figure 1

Shimon Yanowitz
c/o Levy • POB 5009 • Afridar. Ashkelon • Israel 78150
Phone/Fax: ÷972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com
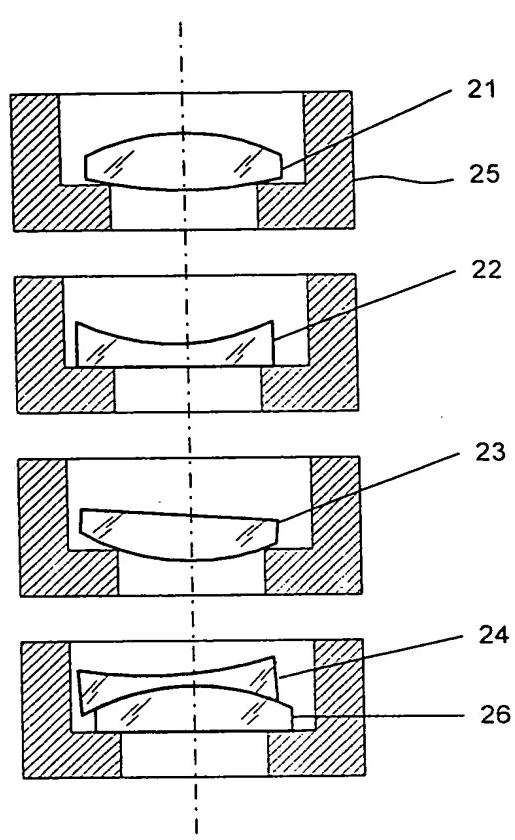
Figure 2

Shimon Yanowitz
c/o Levy • POB 5009 • Afridar. Ashkelon • Israel 78150
Phone/Fax: ÷972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

Page 15 of 22

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: +972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

3./9

Figure 3

Figure 4

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: ÷972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com
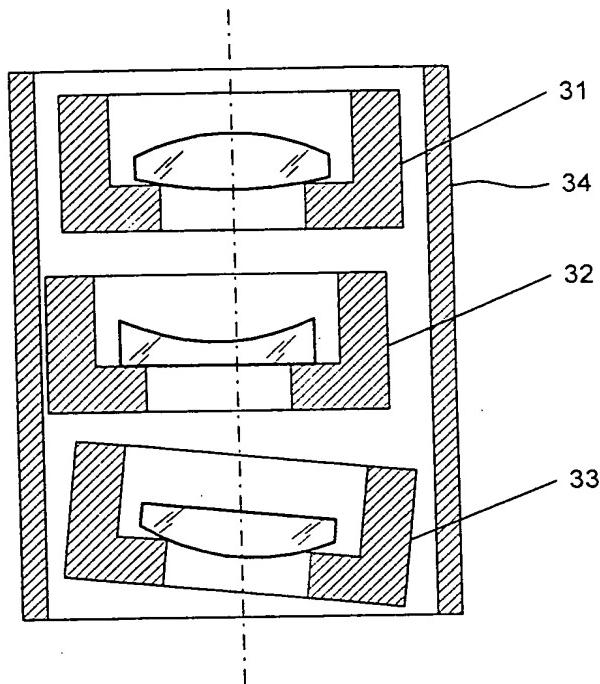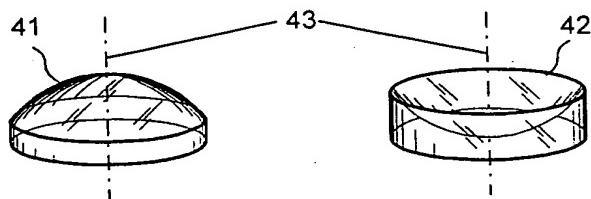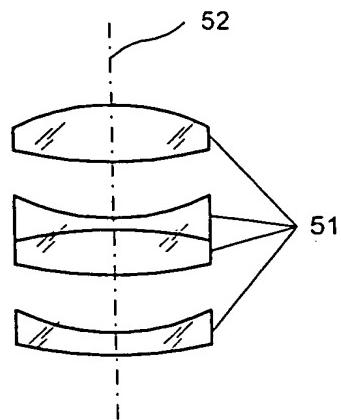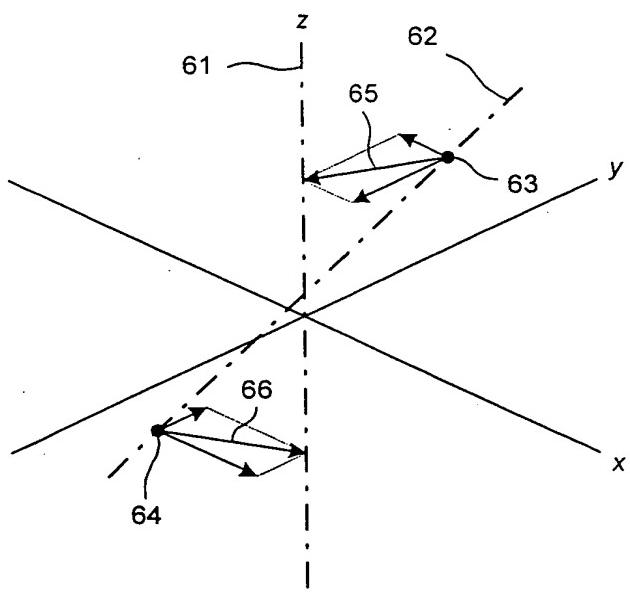
Figure 5

Figure 6

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: +972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

5/9
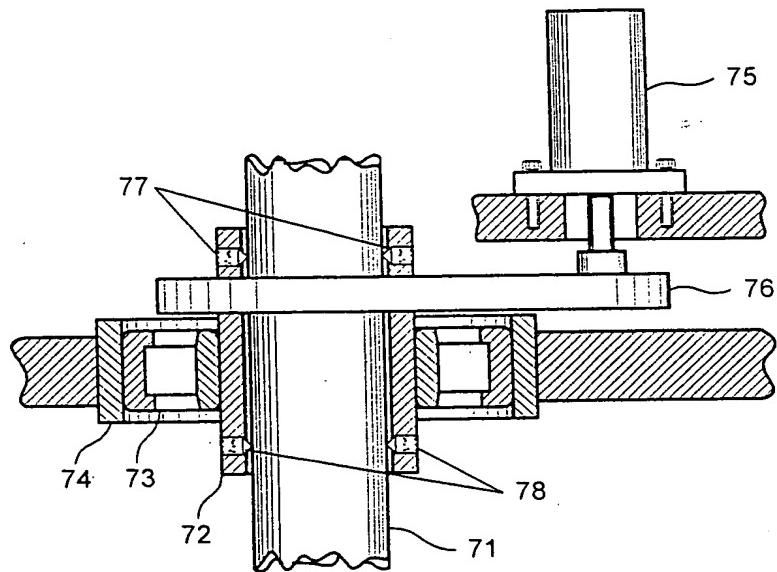
Figure 7

Figure 8

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: +972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

7/9
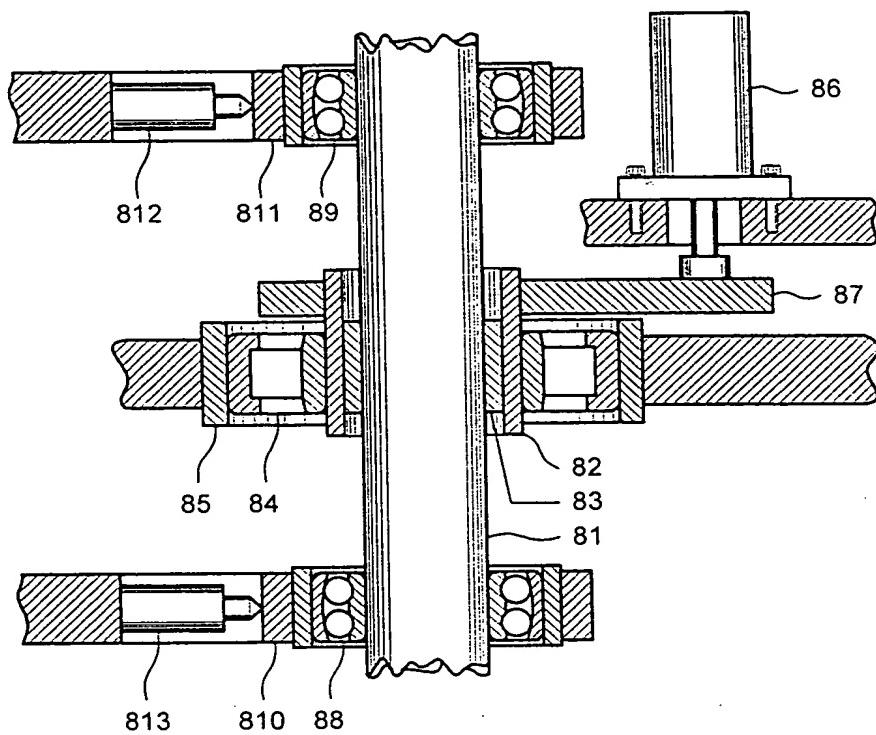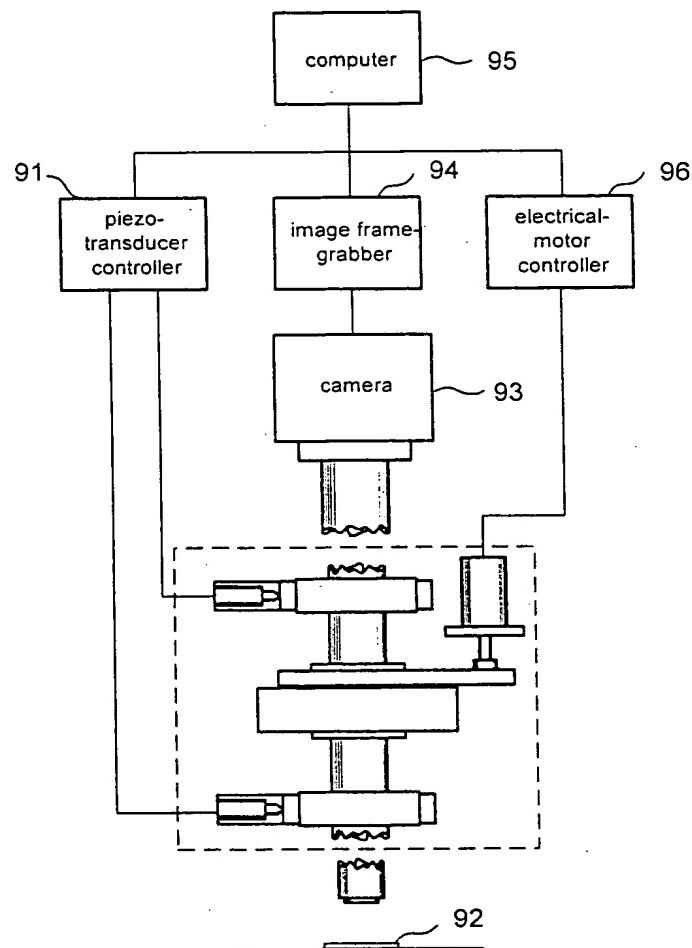
Figure 9

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar. Ashkelon • Israel 78150
Phone/Fax: ÷972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

8/9

computer

image frame-grabber

piezo-transducer controller

electrical-motor controller

103

camera

101

102

Figure 10

Shimon Yanowitz
c/o Lewy • POB 5009 • Afridar, Ashkelon • Israel 78150
Phone/Fax: ÷972-(0)7-6733451 • e-mail: s_d_yanowitz@hotmail.com

9/9

Figure 11